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SOIL EROSION ON CULTIVATED FOOTHILL SLOPES DURING EXTREME RAINFALL EVENTS IN THE WIŚNICZ FOOTHILLS OF SOUTHERN POLAND

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On cultivated foothill slopes soil erosion resulting from short-duration, high-intensity events leads to a distinct transformation of foothill slopes and causes damage to agriculture. The process of intensified water erosion is more significant on commercial farms with a large acreage of crops. This paper presents the geomorphic and economic consequences of three extreme rainfall events which took place at the Jagiellonian University's farmland in the Wiśnicz Foothills of southern Poland in 2002–2006, giving special attention to the influence of land-use patterns on surface and rill erosion processes. Soil erosion by extreme rainfall means the transport of the suspended material downslope and its deposition at the foot of the slopes and in valley bottoms. The resulting loss of soil from farmland may be reflected in the farm's production capacity, triggering an immediate loss of crop in the short term and reduction of yields in the longer term.

Key words: extreme rainfall events, soil erosion, rill erosion, Carpathian Foothills, southern Poland.

1. INTRODUCTION

Soil erosion on the slopes depends on the agricultural use of the area. In the foothill area, almost 95% of land is a private property and an average farm covers an area of ca 3 ha (Guzik 1995). Each farm consisting of a few separate field plots. The mosaic of small fields which are used differently clearly reduces water erosion and makes it intensive only if the slopes are ploughed and unprotected by a dense cover of vegetation. On slopes where agriculture takes place in a sequence of plots that are used differently and separated from one another by elevated boundary strips and transverse furrows, individual plots usually function separately from one another. Movement of material occurs within the plot and accumulates at the downslope portion of the plot, at the transverse furrow, or at the top of the next plot downslope. In effect this creates a distinct flattening at the boundary of the plot and forms an irregular slope profile (Święchowicz 2002). The rate of erosion on small private farms is significantly smaller because natural barriers, such as elevated boundary strips between particular plots, protect the land from the effects of extreme rainfalls. Soil erosion resulting from rainfall is usually most noticeable and spectacular during extreme events like local heavy downpours on intensive farms. Large areas of monoculture farming (sugar-beet, corn) are subject to much more severe water erosion.

Agricultural slopes, devoid of natural vegetation cover, react very quickly to short-duration, high-intensity rainfall events and are one of the most dynamically developing relief forms especially in uplands, foothills or lowlands with only minor topographic differences (Olecki 1970; Teisseyre 1992, 1994; Smolska 1996, 2003; Starkel 1997; Gil 1998; Janicki & Zgłobicki 1998; Rodzik *et al.* 1998; Stankoviansky 2002; Szpikowski 2002; Cerdan *et al.* 2006). Soil erosion rarely happens on all slopes in a catchment simultaneously, and its intensity is differentiated along the longitudinal profile of the slope (Święchowicz 2000, 2004). Soil loss from farmland causes the reduction of the thickness of topsoil layer, leading at times to its complete removal. Erosion not only causes long-term impoverishment of soil and the reduction of crop yield, but also makes farming difficult, and sometimes permanently damages large land areas (Clark, Havercamp & Chapman 1985; Józefaciuk & Józefaciuk 1996; Morgan 1995; Rejman & Rodzik 2006). Additionally, if the cultivated fields are adjacent to built-up areas, those areas are likely to suffer damage as well (Auzet *et al.* 1990; Boardman 1995; Boardman *et al.* 2006; Stankoviansky 2006). The aim of this paper is to present geomorphological and economic effects of three extreme rainfall events in the hydrological years 2002, 2005 and 2006 on agricultural fields on the Jagiellonian University farm and to explain the role of extreme precipitation on slope transformation in the Carpathian Foothills.

2. STUDY AREA AND METHODS

The paper presents the results of research carried out in the lowest part of the Carpathian Foothills, where the Field Research Station of the Institute of Geography and Spatial Management is located. The dominant type of relief is low hills, and the typical surficial material

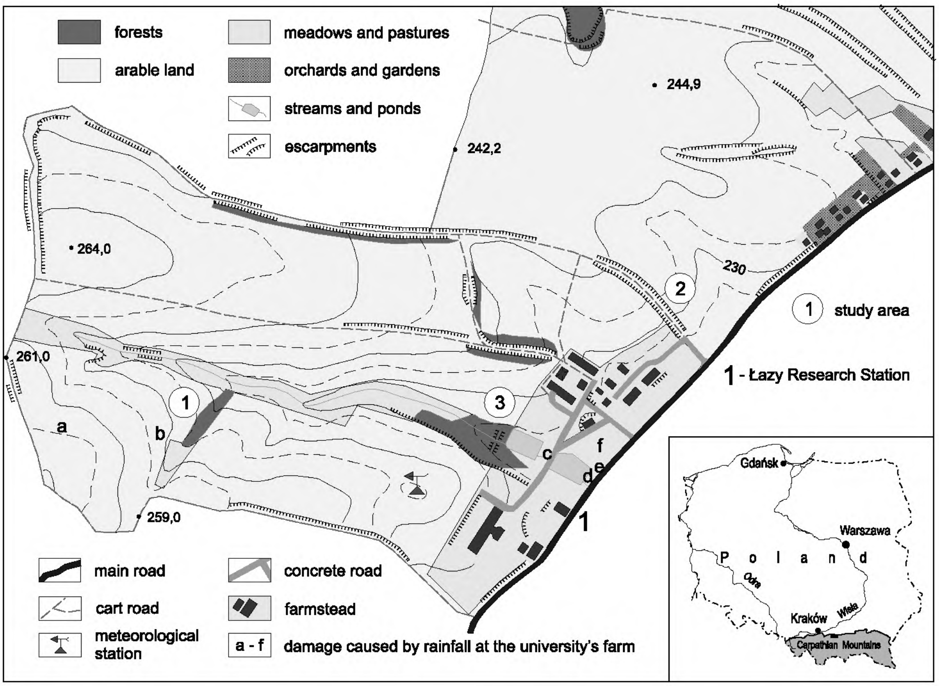


Fig. 1. Location of the study area

for this part of the foothills area is Quaternary silty deposits (Święchowicz 2002).

This study was carried out from 2002 to 2006 by mapping erosion features caused by extreme rainfall events that took place on land managed by the Jagiellonian University (Fig. 1). This land covers an area of 103 ha. The majority of the soils are pseudogley soils (Stagnic Luvisols) developed from lessive soil (Haplic Luvisols) (Klimek 1995). In hydrological years from 2002 to 2006, nearly 86% of the area was used for crops including winter wheat, winter rape and sugar-beet (Fig. 2). The analysis of data collected at the Meteorological Station in Łazy (Fig. 1) during the hydrological years of 1987 to 2006 made it possible to assess the role of extreme rainfall events in slope formation.

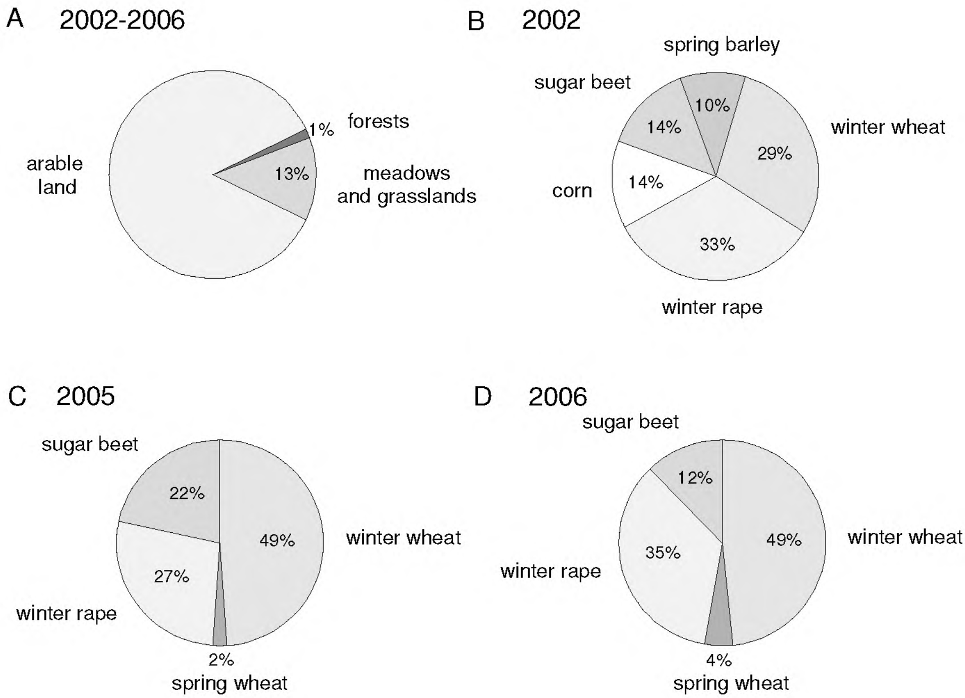


Fig. 2. The Jagiellonian University's farmland in Łazy.
A — land use pattern in 2002–2006, B — agricultural land pattern in 2002, C — agricultural land pattern in 2005, D — agricultural land pattern in 2006

3. EXTREME PRECIPITATION EVENTS

Mean measured annual precipitation from 1987 to 2006 was 657 mm. Annual precipitation totals ranged from 433 mm in 2003 to nearly 800 mm in 1998 and 2001 (Fig. 3A). There were an average of 167.1 days with precipitation in hydrological years 1987–2006. Dominant were days with very weak (0.1–1 mm) and weak (1.1–5.0 mm) precipitation which constituted 76.5% of all the days with precipitation. Days with strong and very strong precipitation (above 20.0 mm) constituted only 3.3% of all the days with precipitation and occurred mainly in the summer. Maximum daily precipitation in a year varied from 21.0 mm in 1993 to 83.4 mm in 2006 (Fig. 3B). During 20 years of observation (1987–2006) rainfalls with daily sums over 40 mm took place 17 times and happened mainly in June (9) when the majority of slopes were sufficiently covered by vegetation. The rainfalls with daily sums 50–60 mm took place four times and happened only in June. The rainfalls 60–70 mm took place only twice in May and in July respectively and the rainfall of daily sum of 83.4 mm (rain gauge) happened only once.

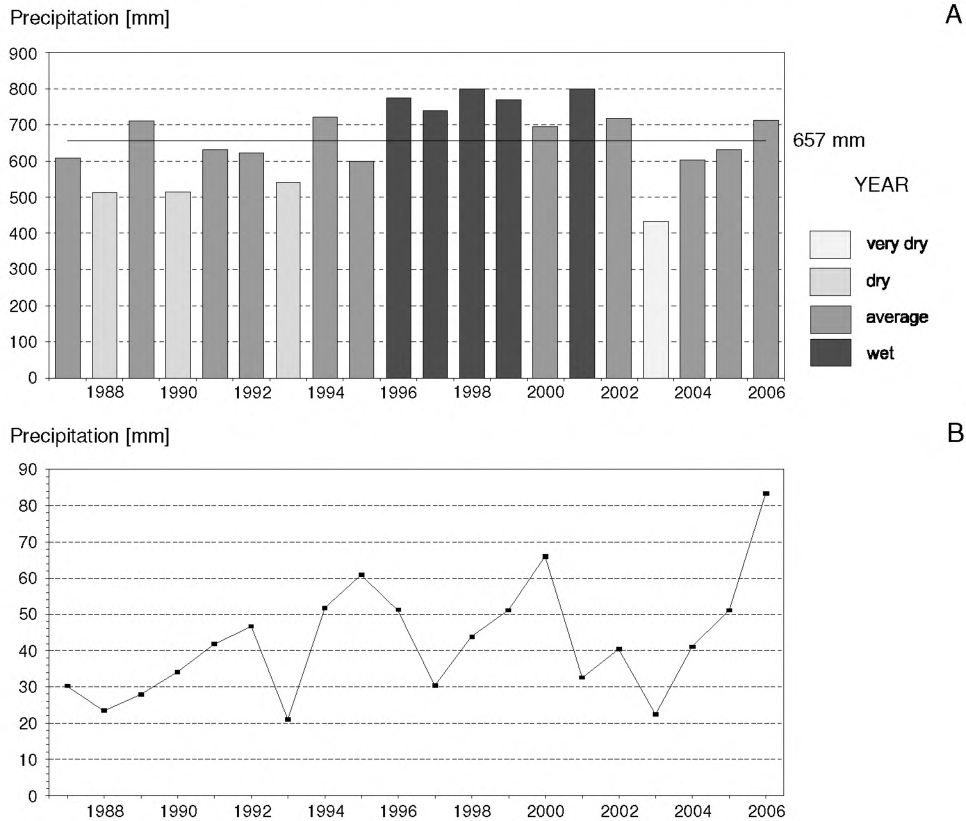


Fig. 3. The characteristics of precipitation in hydrological years 1987–2006 (Łazy Research Station).
A — annual precipitation totals, B — maximum daily precipitation in 1987–2006

4. GEOMORPHIC EFFECTS OF THE EXTREME RAINFALL EVENTS

HYDROLOGICAL YEAR 2002

In 2002, 14% of the agricultural land of the university's farmland was sugar-beet, which was sown in mid-April. The plants germinate within 7–20 days after sowing, and the first leaves started to appear within 7–10 days after germination. When plants formed four leaves, they

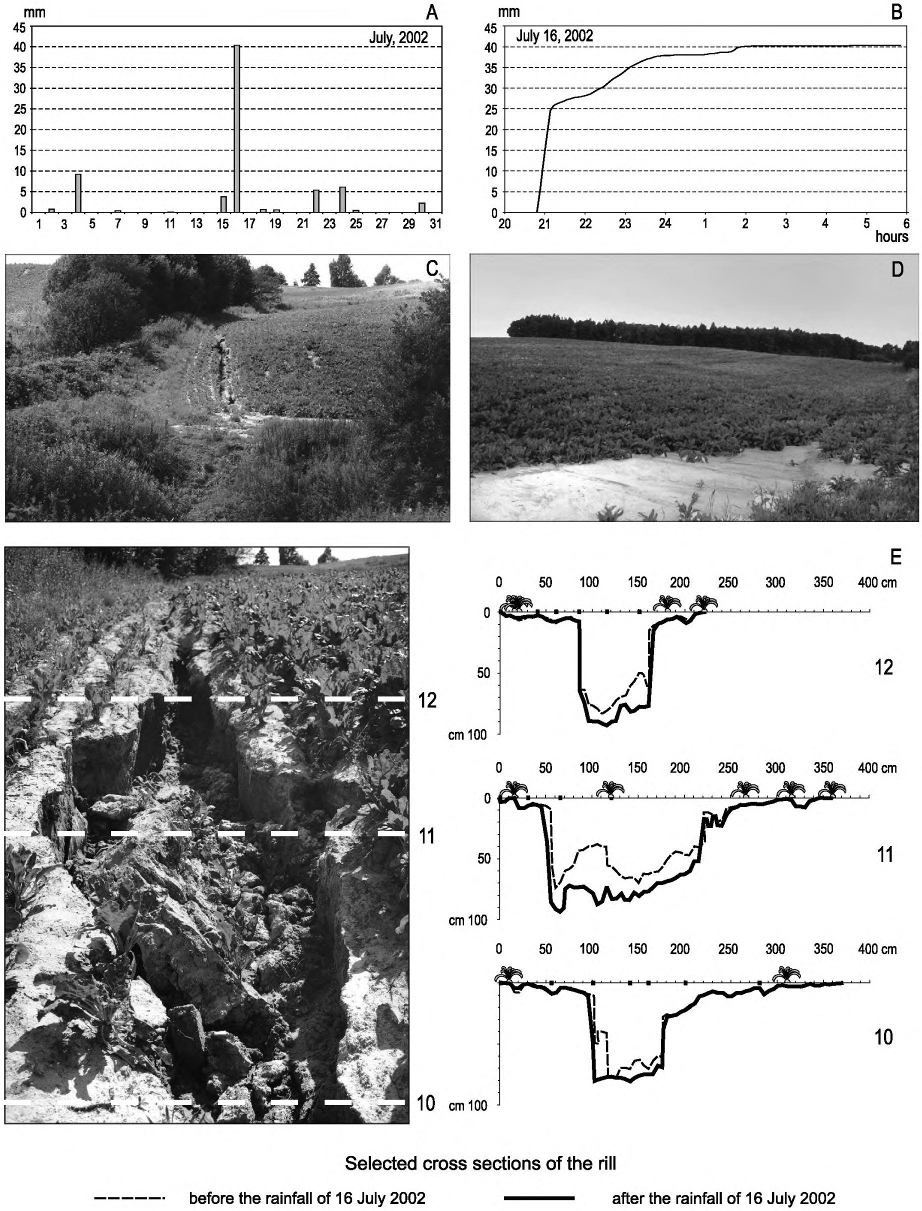


Fig. 4. The characteristics of precipitation in hydrological year 2002 (Łazy Research Station) and the morphological results of intensive rainfall which took place on 16 July, 2002 (phot. by J. Święchowicz).

A — daily precipitation totals in July 2002, B — precipitation total (cumulative) on 16 July, 2002, C — rill on the sugar-beet field in the Dworski Stream catchment, D — deluvial fan in the footslope part of the sugar-beet field in the Dworski Stream catchment, E — selected cross sections of the rill on the sugar-beet field were thinned. As a result, distances between the plants in a row were 20–25 cm. Consequently, the period during which the cultivated land is devoid of a protective cover of leaves is quite long.

On the 29th of May there was rainfall of the amount of 40.2 mm. The result of the rainfall was among others a system of erosion rills which joined to form the main route for transport of water and soil material. In June there were three intensive rainfall events with amounts of 42.7 mm (10–11th June), 30.1 mm (24th June) and 29.2 mm (28th June). After the rainfall of 28th June, the length of the main erosion rill was 30 m, and its maximum depth was 68 cm. On the 16th July there was a 40.4 mm rainfall event, and its intensity within the first 15 minutes was almost 1.3 mm min^{-1} (Fig. 4A, B). As a result of linear slope wash, the main erosion rill deepened to maximum 120 cm and widened in its middle and lower section (Fig. 4C, E; Święchowicz 2004). There was also removal of parts of soil material which broke off its edges and the shift of the erosion rill up the slope. A deluvial fan was built up (Fig. 4D).

Such results were seen only on land with sugar-beet crops. On the remaining slopes the erosion was not noticeable. The eroded material was accumulated in the footslope deluvial plain above the edge which separated it from the valley bottom. The deep erosion rill was an example of the results of linear slope wash on the slope in the catchment. Its formation was a consequence of a rainfall of a significant amount (daily total slightly above 40 mm) which occurred in the initial stage of the plant growth and of sowing of one type of crop on a significant area of the field. Subsequent rainfalls of high amounts and intensities led to the deepening and widening of the existing form irrespective of the vegetation cover (Święchowicz 2004). The eroded rills functioned only in the vegetation season and were removed by tillage.

HYDROLOGICAL YEAR 2005

In 2005, the dominant crop on the Jagiellonian University's farm was sugar-beet, which covered 22% of the arable land. Rainfall events on the 9th and 10th of June had amounts of 14.6 and 51.1 mm respectively (Fig. 5). The result of the rainfall was the deep rill, which became the main route for transport of water and soil material. The deep erosion rill formed only at one location on the field with sugar-beet crop, namely along a cart road going downslope. After the rainfalls in June the maximum depth of the eroded rill was 95.5 cm. The rill was active during the subsequent heavier rainfalls and was deepened dur-

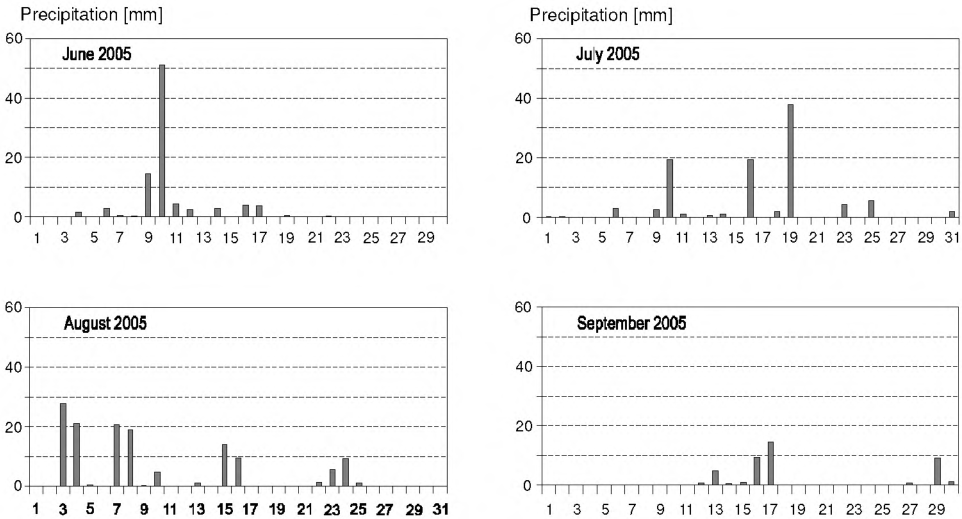
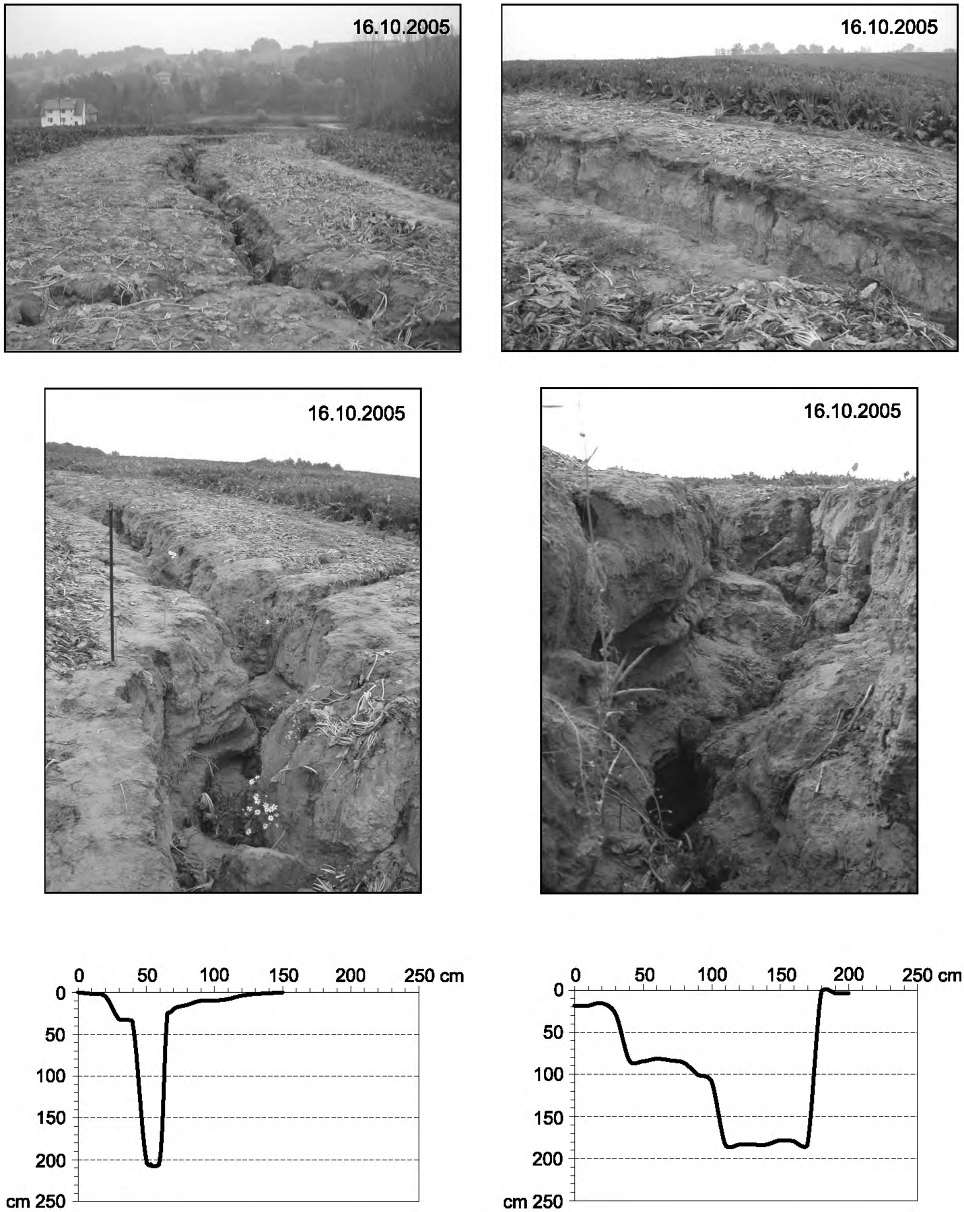


Fig. 5. The characteristics of precipitation in June–September 2005 (Łazy Research Station)

ing the rainfalls in July, August and September (Fig. 5). As a result of linear slope wash the rill deepened to maximum 200 cm and widened in its upper and middle section, with soil material being removed from its edge and the rill shifting up the slope (Fig. 6). The deluvial fan was built up. Such a deep rill was the only example of this type observed on the university's arable land since 1987.

HYDROLOGICAL YEAR 2006

The transformation of the slopes took place on 17th June 2006, during rainfall of the amount of 82.6 mm, which lasted only 85 minutes and its intensity in the first 15 minutes was slightly above 3.8 $mm \cdot min^{-1}$ (Fig. 7). The rainfall caused intensive runoff on the field with sugar-beet, which covered 12% of the crops area in 2006. On an 0.5 ha plot, all the plant seedlings were washed away together with the eroded soil. On the remaining fields with sugar-beets, the crops were silted up and consequently the yields were reduced. The results of the extreme rainfall were most visible on the grape-vine field. The vineyard was established in spring 2005 on the area of 0.3 ha. In spring (May) 2006 grape-vines were planted on additional 0.7 ha. Thus in June when the rainfall took place 0.7 ha of the vineyard was devoid of vegetation



Selected cross sections of the deepest segment of the erosive rill

Fig. 6. The geomorphic results of intensive rainfall which took place in 2005 (phot. by J. Święchowicz)

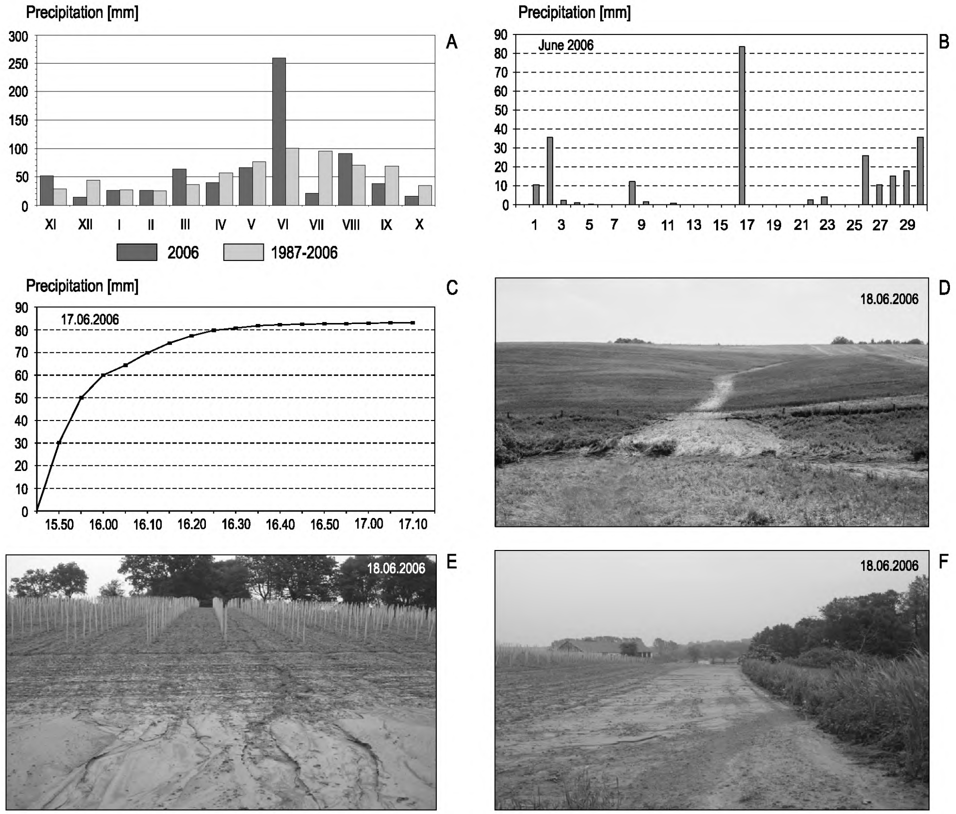


Fig. 7. The characteristics of precipitation in hydrological year 2006 (Łazy Research Station) and the morphological results of intensive rainfall which took place on 17 June, 2006 (phot. by J. Święchowicz).
A — monthly precipitation totals in 2006 to compare with average monthly precipitation totals in 1987–2006, B — daily totals precipitation in June 2006, C — precipitation total (cumulative) on 17 June, 2006, D — the trace of overland flow on wheat field in the Dworski Stream catchment, E — The Dworski Stream catchment — rill erosion on the grape-vine field, F — deluvial deposits at the foot of slope with grape-vine

cover. Between the rows of grape-vine (which were 2.5 m apart) an intensive surface flow took place in several sections. Along the rows of grape-vine rills formed which were typically several to over ten cm deep (Fig. 7E). The eroded material was accumulated in the footslope deluvial plain above the edge which separated it from the valley bottom (Fig. 7F). On the land with cereals there was intensive surface flow too. Yet slope wash was not intensive because of dense vegetation cover.

5. ECONOMIC CONSEQUENCES OF THE EXTREME RAINFALL IN 2006

Extreme rainfalls not only cause changes in the relief and profile of slopes, leading to the build-up of footslope deluvial plains, but also cause financial losses and economic damage. The immediate result of thunderstorm rainfalls and heavy downpours may do damage to farm buildings or infrastructure facilities. The extreme rainfall event caused a lot of damage on the Jagiellonian University's farm. The total damage was estimated to almost 38.5 thousand zloty. As a result of rainfalls, intensive erosion took place on fields where sugar-beet was sown. Although the sugar-beet crop of that year covered only 12% of the farm's arable land, there was considerable damage. On slopes on the area of about 0.5 ha, the sugar-beet plants were totally washed off the field together with the soil (Fig 1, see a), and on the footslope area the soil was accumulated, which brought about the silt-up of crops (Fig. 1, see b). On the remaining sugar-beet fields in the sections of accumulation of the eroded soil the crops were also silted up. The immediate result of the silting-up was that the growth of plants was stopped for 2–3 weeks. This and the subsequent drought in July were responsible for the decrease of the sugar-beet crop yield in 2006 by 45% in comparison to previous years, the damage being estimated to 30 thousand zloty. Such a considerable damage was caused not only by the intensive rainfall but also the conditions of plants' growth. The late and cold spring delayed the sowing. The plants which are usually sown in mid-April, in 2006 were sown at the beginning of May. This means that when the extreme rainfall took place, the plants were too small to withstand the power of water running downslope. Intensive slope wash destroyed the herbicide protection and caused the spread of weeds, which in turn lowered the crop yield.

An insignificant damage was recorded on fields with winter wheat which in 2006 was the dominant crop and covered almost 49% of the arable land. Considerable silting-up of crops took place only on fields with spring wheat, and consequently the crop yield was lowered from 5.5 $t \cdot ha^{-1}$ in 2004 to only 2.0 $t \cdot ha^{-1}$ in 2006. However, due to the small area of that crop (2%), the damage to the cereals were only a small portion of the total damage the farm suffered in 2006 as a result of one extreme rainfall. Despite the high intensity of the rainfall and the accumulation of the washed-off soil in the footslope area covered by the vineyard, there was no damage to the grape-vine plants (Fig. 7 D, E, F). Water flowed freely between the rows forming in several sections erosion rills several to more than ten cm deep. The remaining financial losses resulted from the damage to technical structures or facilities. The pond's dikes (Fig. 1, see c and d) and the fence (Fig. 1, see e) were destroyed and flood waters covered the area of 1 ha (Fig. 1, see f), which later had to be drained.

6. THE ROLE OF EXTREME PRECIPITATION ON SLOPE TRANSFORMATION IN THE CARPATHIAN FOOTHILLS

Short torrential rains play a decisive role in relief transformation in the Carpathian Foothills because during such events substantial amount of soil is transported. Not all relief forms are equally transformed. Top hill areas are least affected, the slopes and valley bottoms — much more. The results obtained confirm regularities occurring in other areas that severe erosion is more intensive when large areas of land are cultivated for one type of crop like sugar beet, rape or corn (Teisseyre 1992, 1994; Rodzik *et al.* 1998). The examples of erosion as presented in this article happened on one of only a few big farms which use large-scale intensive agriculture in the Wiśnicz Foothills. During the study area, the majority of the farm were arable fields (86%) used for sugar-beet, rape or corn crops. It was the sugar-beet field that underwent the most intensive slope transformation which resulted in the formation of rills and gullies, and the accumulation of deluvia in the footslope areas. New erosive forms were not permanent as they were removed by tillage after the sugar-beet harvest. However, soil eroded from the field was permanently accumulated in the form of deluvial fans at the foot of the slope or in the valley bottom.

When the slopes are separated from valley bottoms with a distinct edge, the eroded material is accumulated in form of deluvial fans above the edge. It causes a buildup and widening of footslope parts. A clear morphological contrast between the slopes and the bottom of the valley is thus created. When the slopes gently transform into valley bottoms without a distinct edge and the land is ploughed up and down slope, the deposition of the material at the foot or in the valley bottom causes lengthening of the concave sections of the slope and as a result morphological contrasts between the slopes and the valley bottom become blurred (Święchowicz 2002, 2006).

It is worth emphasising that in the Carpathian Foothills dominant are small farms which cover the area of 3 ha on average and are divided into several plots. The adjacent plots are differently used. Foothill areas, due to short and gentle slopes and low infiltration of soil cover, have a longitudinal pattern of plots without stable transverse boundary strips. A stable pattern of small plots separated by boundary strips limits the effectiveness of erosion (Święchowicz 2002). On the other hand, as research carried out in Slovakia shows, getting rid of a traditional pattern of fields as well as boundary strips and escarpments and the introduction of large-scale intensive agriculture accelerates soil erosion (Stankoviansky 2002, 2006).

The Carpathian Foothills are also likely to undergo large-scale processes resulting from the restructuring of agriculture. Small individual farms will gradually give way to large commercial farms with monoculture crops. The traditional pattern of plots and the protective network of elevated boundaries and escarpments will slowly disappear. These changes will accelerate water erosion on agricultural slopes and will also be responsible for causing damage.

7. CONCLUSIONS

Soil erosion is a slow process which takes place seldom and continues relatively unnoticed. Only sporadic short-duration and high intensity rainfall events may trigger severe soil erosion causing serious loss of topsoil. The process leads to significant changes of the forms already present on the slope and to the formation of rills and gullies, and the material transported down the slope is accumulated on the footslope plains or in the valley bottom in the form of deluvial fans. Deposition of the material at the bottom of the slope and in the valley floor leads to the elevation and extension of the valley bottom and hindering thereby transport of solid material from the slope to the channel. Consequently, slope-channel coupling and material supply becomes only local and episodic.

However, erosion features that formed as a result of soil erosion on the slopes were not permanent. They occurred only in the growing season and were removed by tillage. Soil erosion rarely happens on all the fields simultaneously and its intensity is differentiated along the longitudinal profile of the slope. In the transformation of slopes a greater role is played by land use, the area of crops and how big the crops are during the rainfall rather than by the parameters of rainfall. Identical rainfall (same amount, intensity and duration) causes different results depending on land use. Soil resistance to erosion depends on the type of crops and spatial crop structure. Soil erosion caused by extreme rainfall events is more serious on large areas of monoculture farming.

The loss of soil from farmland may be reflected in the immediate loss of crop and yield reduction in the longer term. However, the immediate losses or damage do not always have to be the result of extreme rainfall only. Sometimes a greater influence on the size of damage in agriculture may have type of crops and weather conditions (temperatures and rain) just before the occurrence of intensive rainfalls or immediately afterwards.

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